BIOFICATION OF BUILDINGS: A NEW SOLUTION BEYOND STRUCTURAL CONTROL

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ABSTRACT:
Sustainability of urban systems is dependent on knowing in a quantitative manner conditions such as level of deterioration and level of safety of major structures. Sensors are key devices for acquiring such necessary information, but in addition it is required that there be technology to extract only the relevant information from the tremendous amount of sensor gathered data. The structural health monitoring (SHM), ascendant in civil engineering, has been studied and developed in our laboratory for several years. Our SHM system consists of a smart sensor network (for data acquisition), a database server (for data storage and data management), and diagnosis and prognosis applications.

Civil engineering sensors and networks, however, can be extended to more novel roles -- detecting and recording the histories of environmental conditions of structures. Among many potential applications, we are particularly interested in using robots as moving sensor agents, that we call sensor agent robots, to gather information on buildings and residents. The information obtained by the sensor agent robots is used to record life phases of the environment relevant to buildings. The information is then transformed to “genes” to be passed the important information to future “generations” of buildings. We call this concept “biofication of buildings” and are working to integrate the concept.

The “biofication of buildings” shall be our new research target beyond structural control. This paper briefly introduces the outline of this concept and some preliminary experiments.

KEYWORDS:
structural control, health monitoring, smart sensor, pattern recognition, genes

1. INTRODUCTION

Prof. Takuji Kobori, my master thesis advisor at Kyoto University, initiated a new research field “structural control” after he moved to a large construction company as executive vice president. He eventually developed the world-first active mass dampers to reduce the response of a building against wind loading and moderate earthquake loading. That was the point when structural engineering researchers started learning new engineering tools such as modern control theory, signal processing and system identification. As a research engineer, I had been excited about the arrival of new technology frontier.

At present, more than 40 buildings in Japan have active mass dampers of many types. Passive structural control systems have become a standard solution for tall buildings to be safer and more sustainable. However, we realized that the active structural control systems are not almighty. Active mass dampers are mainly used for keeping comfortable vibration level for strong winds. Thus most devices are applied to tall buildings with hotel rooms in upper floors.

To evolve Prof. Kobori’s efforts, I feel it is the time to extend his vision and passion to a new research area. Thus I would like to propose “biofication of buildings” to fully utilize new technologies and quickly evolve our building systems.

2. BIOFICATION OF BUILDINGS

A smart sensor network can be an infrastructure for detecting and recording the histories of environmental conditions relevant to buildings beyond structural health monitoring. Among many potential applications, we are particularly interested in using it mounted on robots as moving sensor agents, that we call “sensor agent robots”, to gather information from buildings and residents. The information obtained by the sensor agent robots is used to record all activities in the living spaces as “genes” in the form of DNA, to transform the living spaces and its genes, and to pass on the information to future “generations” of buildings. We call this concept “biofication of buildings”, and we are working to evolve the concept and the generation of such “genes”. The sensor agent robots can work as actuators in many incidents as well. The smart sensor network including sensor agent robots will be the key in this concept as illustrated in Figure 1.

In designing a building, we usually rely on the designer’s knowledge and experience to decide its specifications such as the ceiling heights, the locations of electric outlets, the room layouts and so on. However, it may not satisfy the real needs of the residents. In most cases, they do not know what their real needs are. It is truly difficult to know the ideal specifications for the building. Gathering environmental information relevant to how to use the building will change the way of designing of a building from experience-based to data-based design. Thus buildings will evolve much faster and will meet the real needs of their residents. The DNA embedded in a building will be used for converting the recorded environmental information to data needed to design new generations. The data expressed in the form of design drawings will be of another form. Using DNAs of many buildings, we will be able to have variety of buildings without tedious design processes.

Our human body has another important feature called immune system. It is the system to distinguish between my cell and other cells. If harmful other cells are found, the immune system will attack them in many ways. We would like to embed this concept into a building. This system can work as alarm system to detect an intruder into a room. It will detect some unusual incidents such as the damage due to fire, typhoon or earthquake. For a room where an elderly person lives, it will act as a guard for him or her. Thus, the immune system embedded in a building help create a safer, securer and more comfortable spaces for us.

Sensors will play a key role in this new research field. Logging any data of the buildings and the residents will be the sources of evolving the structures as well as their smartness.

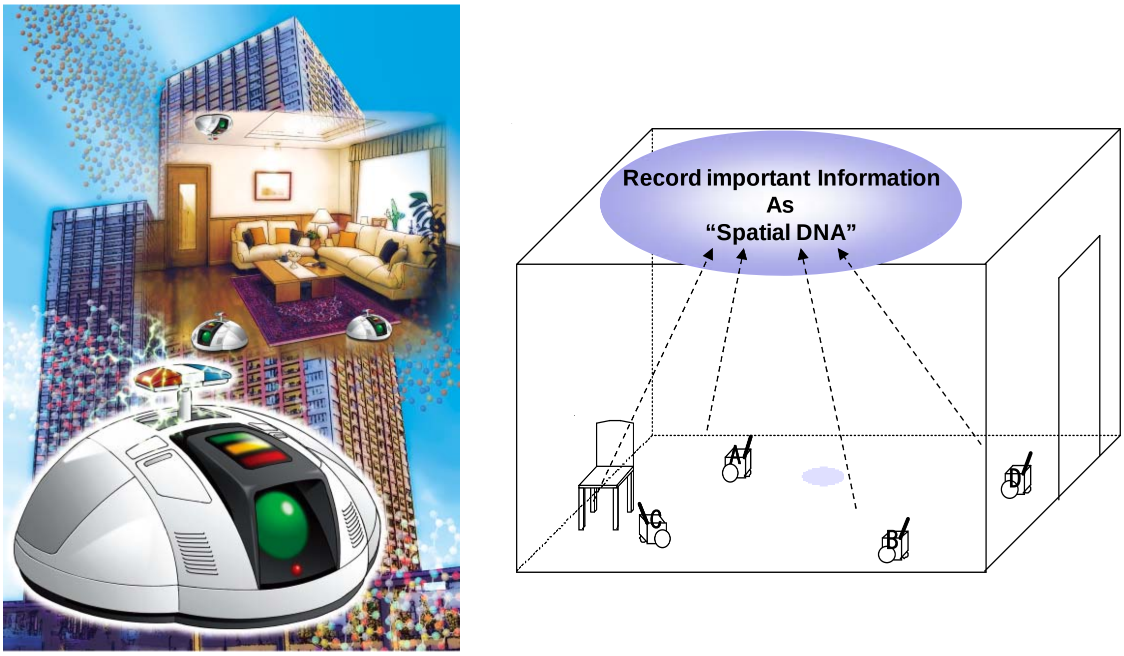

Figure 1 Image of biofication of building

3. SMART SENSOR FOR BIOFICATION

For sensing environments in buildings, we have recently developed a smart sensor unit to be used in the smart sensor network with an automatic configuration mechanism. The smart sensor unit communicates readily with the server to configure the sensor unit automatically. The key components of the system are i) a smart sensor unit, ii) a data model, and iii) a user data management. The mechanism of the proposed sensor network to achieve automatic configuration is described as follows:

- A smart sensor unit with a brain communicates with other sensors as well as the server.
- All specifications associated with the smart sensor unit are stored in the memory so that once the network is connected all the necessary data are automatically fed to the server.
- All meta-data including the sensor configuration are stored in the database. The raw data are linked to the meta-data models so that easy and fast data selection is possible.
- Easy-to-use user interfaces are developed using php, and the configuration of the sensor network can be also conducted through this user interface.

The smart sensor unit depicted in Figure 2 consists of three boards: i) a micro-network terminal SUZAKU-V board, ii) a power supply board, and iii) a sensor board with an A/C converter. The physical dimension of this unit including the sensor case is 5 cm (H) × 8 cm (W) × 10 cm (L). Although any sensor can be applicable to this unit, a servo-accelerometer was selected for the prototype system. The accelerometer can measure in three orthogonal directions simultaneously.

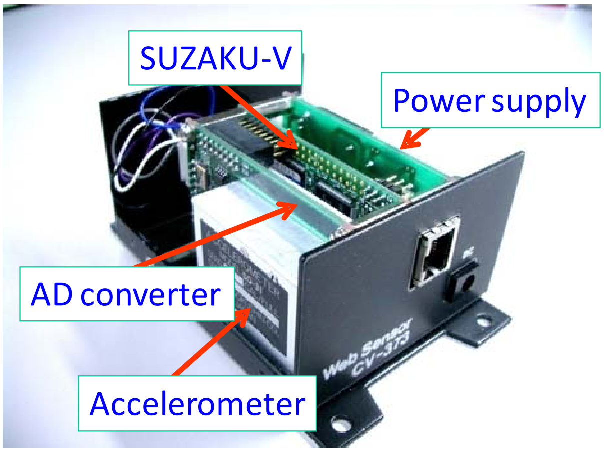

Figure 2 Smart sensor consisting of network terminal SUZAKU-V, accelerometer and power supply board

3. RECOGNITION OF HUMAN BEHAVIORS USING PYROELECTRIC INFRARED SENSOR

Among environments associated with buildings, knowing the human behaviors has important roles in designing building spaces. By knowing the human behaviors, we will be able to conduct the most efficient planning of rooms and can provide appropriate functions. However, measuring the human behaviors considering the privacy of residents is a difficult task. The use of surveillance cameras is not preferred in private rooms. Thus we decided to employ simple and less troublesome systems. The first example is a group of pyroelectric infrared sensors as they will not emit any lights or radio waves and the size is very small. They are already accepted in many residential rooms to turn on the lights by detecting the motion of a human. However, they only provide existence of motion and do not tell the details of motions such as the direction of motion and the speed of motion. We would like to extract more information from the pyroelectric infrared sensors.

We conducted preliminary experiments for possible recognition of human behaviors using pyroelectric infrared sensors. An image of human passage in front of a pyroelectric infrared sensor is shown in Figure 3. The information on walks, such as speed is extracted as a "meaning" of measurement data. As shown in the left figure of Figure 3, walking patterns of people passage through a sensor front are measured. The sensing range of the pyroelectric infrared sensor can be controlled by an optical system as shown in the right figure of Figure 3. The measurement distance was designed to be 5m and angular range to be ±5 degrees. The pyroelectric infrared sensor used for this test is a dual element type. In order to remove the bias such as the sunlight, a positive element and a negative element are connected in series in the dual element type sensor. The measured walk patterns are 25 patterns shown in Figure 4 plus one pattern that is motionless. Thus the total number of patterns considered here is 26. Each pattern was repeated 10 times. The motionless pattern and the No.1 to No. 10 patters are used as learning data. The samples of measured time histories for the pattern 1, 2, 3, 6 and 7 are plotted in Figure 5. The details of the experiment are available in Shimoyama and Mita (2008).

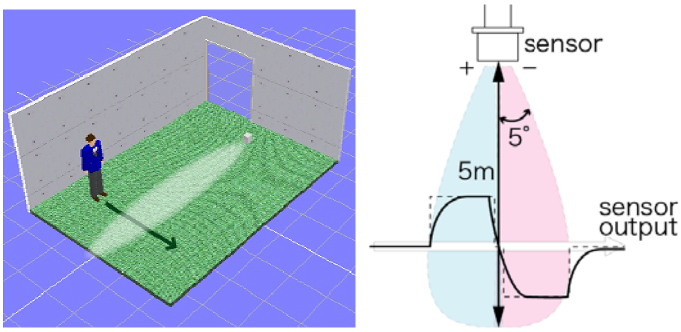

Figure 3 Image of human passage in front of pyroelectric infrared sensor

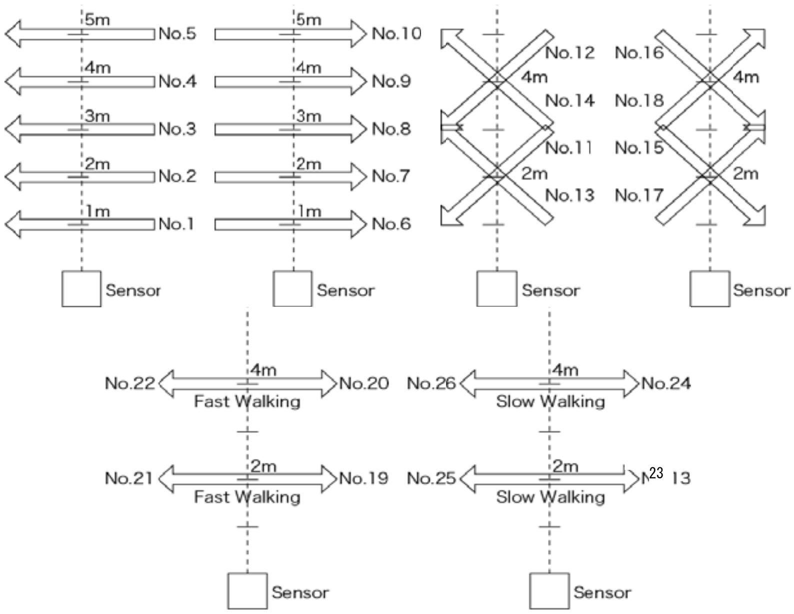

Figure 4 Walking patterns used in the experiment

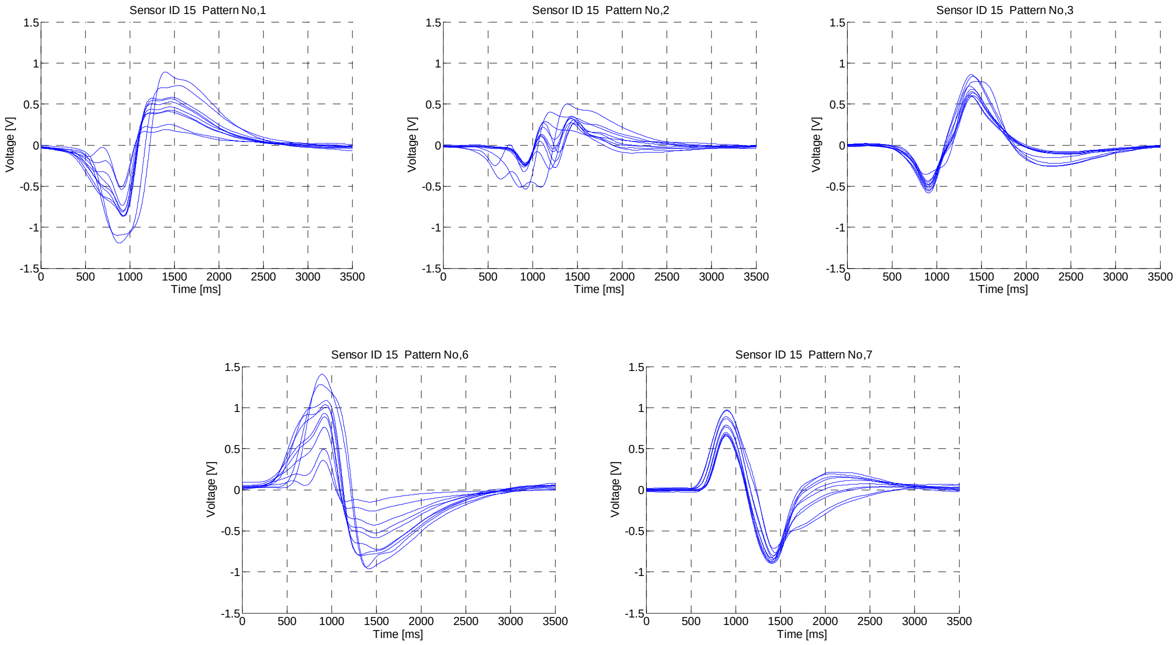

Figure 5 Output waveforms of pyroelectric infrared sensor

We applied wavelet transformation to the time histories. It turned out that the frequency components become higher when the walking speed is fast. Moreover, wavelet coefficient intensities were found affected by the distance from the sensor from a passage position. Thus we picked up the first peak value (maximum or minimum) and the peak magnitude of wavelet analyzed waveforms in the specific frequency of the scale factors 133, 667, and 1333. They were used as features in this study. The features are summarized in Table.1. Applying the nearest neighbor method, we evaluated the distance of the passage from the sensor. The results are summarized in Table 2 and Figure 6. We could see high success rate with this simple mechanism. We believe that more information with respect to human behaviors will be extracted using pyroelectric infrared sensors. They are very promising sensing tool.

Table.1. Features used for recognition

Feature value		Scale factor
Intensity of Wavelet coefficients	First peak	133(5.0Hz)
		667(1.0Hz)
		1333(0.5Hz)
	Maximum amplitude	133(5.0Hz)
		667(1.0Hz)
		1333(0.5Hz)

※Normalized with the average of absolute value

Table.2. Success rate for recognition

		Sensor ID			
		14	15	16	17
Patterns used for learning	Precise	80.91%	95.46%	86.36%	80.00%
	±1m error	99.10%	98.18%	97.27%	97.27%

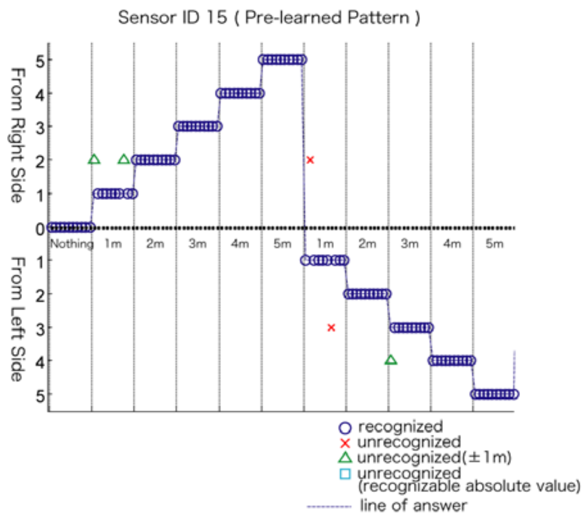

Figure 6 Recognition of distance between the sensor and the target human

4. RECOGNITION OF HUMAN BEHAVIORS USING ACCELEROMETER

As the second step we conducted experiments for recognizing human behaviors using accelerometers placed on the room floor. The vertical acceleration of the floor is measured when a human is walking beside the sensor. The accelerometer can be very small in size so that it can be embedded into the floor panels.

We selected 4 footstep parameters as components of feature vectors. They are listed below. We expected these parameters reflect the personal information, like their physical and functional characteristic. For example, stride length was strongly associated with height length. All these parameters were calculated only from the acceleration data. An example of acceleration data is plotted in Figure 7. From our preliminary experiments, we found that we will be able to identify who is walking and what he or she is doing during walk. Thus, accelerometer is another promising sensor for human behavior recognition.

(1) walking velocity
Walking velocity was calculated based on the international standard of measuring. Individuals have their own walking velocity called “free walking velocity”. It is closely related to both their physical and functional balance.

(2) stride length
It depends on the personal height, leg length and walking velocity.

(3) cadence
This word indicates the number of footsteps per minute. Both legs swing by a particular cycle which is inverse proportional to leg length. This means the height of walker become lower, the cadence become higher.[2]

(4) time ratio between stance period and swing period
The time from the first contact between foot and ground to next contact is called “walking cycle”. This cycle is divided into two time phases. One is “stance period” and the others is “swing period”. The proportion of them is known that stance: swing = 6 : 4.

Stance period: the period when leg get in touch with ground
Swing period: the period when leg is brought to front direction by swing.

The detailed discussion on recognizing human behavior using accelerometers is available in Hasumi and Mita (2007).

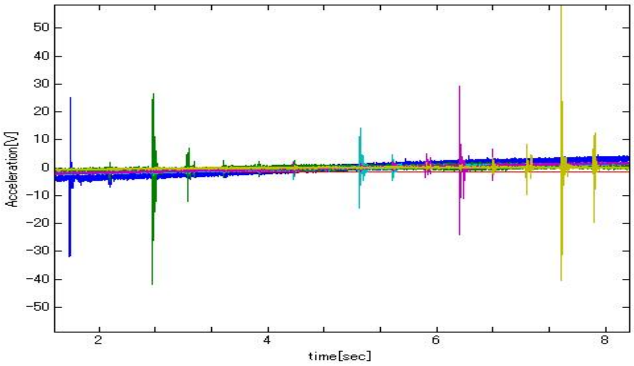

Figure 7 Acceleration time histories for human walking

4. CONCLUSION

As an evolution of structural control research, a new concept “biofication of buildings” was presented. In this concept, sensor network systems will play a key role to gather all environmental data associated with buildings. The environmental data include not only structural conditions but also human behaviors and interaction between human and building systems. By accumulating all such information, we would like to make “genes” for buildings in the form similar to DNA.

Two preliminary tests were presented here to obtain the information of human behaviors using pyroelectric infrared sensors and accelerometers. Both test results showed good potential of proposed mechanisms. We would like to explore this new research area and hopefully we will be able to report some initial and interesting research results in the near future.

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